AMENDED CLAIMS

[received by the International Bureau on 12 February 2004 (12.02.04); original claims 1 and 10 amended; remaining claims unchanged

1. A nuclear magnetic resonance (NMR) logging apparatus for use in a borehole for determining properties of an earth formation surrounding the borehole, the apparatus comprising:
   (a) a magnet for inducing a static magnetic field in a region of interest in the earth formation;
   (b) a transmitting antenna assembly for inducing a radio frequency magnetic field within said region of interest and producing signals from materials in the region of interest; and
   (c) a receiving antenna assembly for detecting said signals from said region of interest;

   wherein at least one of the antenna assemblies includes at least one magnetic core formed from a non-ferritic material having low magnetostriction.

2. The NMR logging apparatus of claim 1 wherein said material has a high internal damping and further comprises a powdered soft magnetic material.

3. The NMR logging apparatus of claim 2 wherein the powdered soft magnetic material is non-conductive and has a maximum grain size to substantially reduce intragranular power loss at a frequency of said radio frequency magnetic field.

4. The NMR logging apparatus of claim 2 wherein the powdered soft magnetic material has a maximum grain size less than half a wavelength of an acoustic wave having a frequency of said radio frequency magnetic field.

5. The NMR logging apparatus of claim 1 wherein said material has a high internal damping and further has a large area within a hysteresis loop associated with magnetostrictive deformation of the material.

6. The NMR logging apparatus of claim 2 wherein said at least one antenna

core further comprises a non-conductive bonding agent having substantial acoustic decoupling between grains.

7. The NMR logging apparatus of claim 1 wherein said logging apparatus is adapted to be conveyed on one of (i) a wireline, and, (ii) a drilling tubular.

8. The NMR logging apparatus of claim 1 wherein said material has a low magnetostriction and comprises an amorphous metal.

9. The NMR logging apparatus of claim 1 wherein the transmitting antenna assembly and the receiving antenna assembly are the same.

10. A method of determining properties of an earth formation surrounding a borehole, the method comprising:

(a) using a magnet on a nuclear magnetic resonance (NMR) logging apparatus conveyed in the borehole for inducing a static magnetic field in a region of interest in the earth formation;

(b) using a transmitting antenna assembly for inducing a radio frequency magnetic field within said region of interest and producing signals from materials in the region of interest; and

(c) using a receiving antenna assembly for detecting said signals from said region of interest;

the method further comprising using a core for at least one of the antenna assemblies formed from a non ferritic material having low magnetostriction.

11. The method of claim 10 wherein said material has a high internal damping, the method further comprising using a powdered soft magnetic material as said material with high internal damping.

12. The method of claim 11 further comprising selecting the powdered soft magnetic material to be substantially non-conductive and having a maximum

grain size to substantially reduce intragranular power loss at a frequency of said radio frequency magnetic field.

13. The method of claim 11 further comprising selecting the powdered soft magnetic material as having a maximum grain size less than half a wavelength of an acoustic wave having a frequency of said radio frequency magnetic field.

14. The method of claim 10 wherein said material has high internal damping, the method further comprising selecting said material as having a large area within a hysteresis loop associated with magnetostrictive deformation of the material.

15. The method of claim 11 further comprising using in said at least one antenna core a non-conductive bonding agent having substantial acoustic decoupling between grains.

16. The method of claim 10 further comprising conveying said NMR logging apparatus into said borehole on one of (i) a wireline, and, (ii) a drilling tubular.

17. The method of claim 10 wherein said material has a low magnetostriction, the method further comprising selecting an amorphous metal for use as said material.

18. The method of claim 10 further comprising using the same antenna for the transmitting antenna and the receiving antenna.

19. An apparatus for evaluating electrical properties of an earth formation surrounding a borehole, the apparatus comprising:

(a) a transmitting antenna assembly for conveying a radio frequency

electromagnetic field into said earth formation; and

(b) a receiving antenna assembly for receiving a signal resulting from interaction of said electromagnetic field with said earth formation;

wherein at least one of the antenna assemblies includes at least one of: (I) a magnetic core formed from a material having high internal magnetostrictive damping, and, (II) low magnetostriction.

20. The apparatus of claim 19 wherein said material has a high internal damping and further comprises a powdered soft magnetic material.

21. The apparatus of claim 20 wherein the powdered soft magnetic material is non-conductive and has a maximum grain size to substantially reduce intragranular power loss at a frequency of said radio frequency magnetic field.

22. The apparatus of claim 20 wherein the powdered soft magnetic material has a maximum grain size less than half a wavelength of an acoustic wave having a frequency of said radio frequency magnetic field.

23. The apparatus of claim 19 wherein said material has a high internal damping and further has a large area within a hysteresis loop associated with magnetostrictive deformation of the material.

24. The apparatus of claim 20 wherein said at least one antenna core further comprises a non-conductive bonding agent having substantial acoustic decoupling between grains.

25. The apparatus of claim 19 wherein said apparatus is adapted to be conveyed on one of (i) a wireline, and, (ii) a drilling tubular.

26. The apparatus of claim 19 wherein said material has a low magnetostriction and comprises an amorphous metal.

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27. A method of determining a resistivity parameter of an earth formation surrounding a borehole, the method comprising:

(a) using a transmitting antenna assembly on a tool conveyed in said borehole for transmitting a radio frequency electromagnetic field into said earth formation;

(b) using a receiving antenna assembly for receiving a signal resulting from interaction of said electromagnetic field with said earth formation;

(c) using a core for at least one of the antenna assemblies for enhancing the received signals, said core formed from a material having at least one of (I) high internal magnetostrictive damping, and, (II) low magnetostriction.

28. The method of claim 27 wherein said material has a high internal damping, the method further comprising using a powdered soft magnetic material as said material with high internal damping.

29. The method of claim 28 further comprising selecting the powdered soft magnetic material to be substantially non-conductive and having a maximum grain size to substantially reduce intragranular power loss at a frequency of said radio frequency magnetic field.

30. The method of claim 28 further comprising selecting the powdered soft magnetic material as having a maximum grain size less than half a wavelength of an acoustic wave having a frequency of said radio frequency magnetic field.

31. The method of claim 27 wherein said material has high internal damping, the method further comprising selecting said material as having a large area within a hysteresis loop associated with magnetostrictive deformation of the

material.

32. The method of claim 28 further comprising using in said at least one antenna core a non-conductive bonding agent having substantial acoustic decoupling between grains.

33. The method of claim 27 wherein said material has a low magnetostriction, the method further comprising selecting an amorphous metal for use as said material.

34. The method of claim 27 wherein said tool is conveyed into the borehole on one of (i) a wireline, and, (ii) a drilling tubular.

35. An apparatus for evaluating electrical properties of an earth formation surrounding a borehole, the apparatus comprising:

(a) a transmitting antenna assembly for conveying an electromagnetic field into said earth formation; and

(b) a receiving antenna assembly for receiving a signal resulting from interaction of said electromagnetic field with said earth formation;

wherein at least one of said antenna assemblies includes at least one magnetic core formed from a non-ferritic powdered soft magnetic material having high saturation flux density and a non-conductive bonding agent, said magnetic core having a magnetic permeability $:_m$ less than 500 and wherein said saturation flux density is greater than about 0.4 T.

36. The apparatus of claim 35, wherein the magnetic core further comprising dimensions which are related to the direction of an RF magnetic field produced by the transmitter coil and to the magnetic permeability of the powdered soft magnetic material.

37. The apparatus of claim 35 wherein the powdered soft magnetic material is

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conductive and has a maximum grain size to substantially prevent intragranular power loss of said transmitted electromagnetic signal.

38. The apparatus of claim 35 wherein an effective demagnetizing factor of the magnetic core in a direction of the radio frequency magnetic field substantially exceeds the inverse magnetic permeability of the powdered soft magnetic material.

39. The apparatus of claim 36, wherein the core has an effective permeability, μ, less than 5, as defined by a first equation,

$$\mu = 1 + (\mu_m - 1) / ((\mu_m - 1) \cdot D + 1),$$

wherein D, the demagnetizing factor can be estimated from an elliptic equivalent of the cross-section of the core, as defined by a second equation,

$D = S_x / (S_x + S_y)$,

wherein Sx and Sy represent the elliptic equivalent dimensions in horizontal and vertical dimensions respectively, in a plane the core.

40. The apparatus as defined in claim 35 wherein the powdered soft magnetic material possesses a maximum magnetic permeability given a predetermined maximum RF antenna power loss.

41. The apparatus of claim 35 wherein said flux density is greater than that of a magnetic core consisting primarily of ferrite.

42. The apparatus of claim 35 wherein the magnetic core further comprises relative dimensions that are related to the direction of the RF magnetic field and to the magnetic permeability of the powdered soft magnetic material.

43. A method of making measurements of a parameter of interest of an earth formation comprising:

(a) conveying a logging tool into a borehole in said earth formation;

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(b) using a transmitter antenna assembly on the logging tool for conveying an electromagnetic field into the earth formation;

(c) using a receiver antenna assembly for detecting signals resulting from interaction of said electromagnetic field with said earth formation, and

(d) including in at least one of the antenna assemblies a magnetic core formed from a non-ferritic powdered soft magnetic material having high saturation flux density and a non-conductive bonding agent, said magnetic core having a magnetic permeability $:_m$ less than 500 and a saturation flux density greater than about 0.4T.

44. The method of claim 43 further comprising selecting dimensions for the magnetic core which are related to the direction of the magnetic field and to the magnetic permeability of the powdered soft magnetic material.

45. The method of claim 43 further comprising selecting relative dimensions for the magnetic core which are related to the direction of the magnetic field and to the magnetic permeability of the powdered soft magnetic material

46. The method of claim 43 wherein the powdered soft magnetic material is conductive, the method further comprising selecting a maximum grain size for the soft magnetic material to substantially prevent intragranular power loss of said radio frequency magnetic field.

47. The method of claim 43 wherein an effective demagnetizing factor of the magnetic core in the direction of the magnetic field substantially exceeds the inverse magnetic permeability of the powdered soft magnetic material.

48. The method of claim 47, wherein the core has an effective permeability, μ, less than 5, as defined by a first equation,

$$\mu = 1 + (\mu_m - 1) \; / \; ((\mu_m - 1)\cdot D + 1),$$

wherein D, the demagnetizing factor can be estimated from an elliptic

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equivalent of the cross-section of the core, as defined by a second equation,

$$D = S_x / (S_x + S_y),$$

wherein Sx and Sy represent the elliptic equivalent dimensions in horizontal and vertical dimensions respectively, in a plane the core.

49. The method of claim 43, wherein the powdered soft magnetic material possesses a maximum magnetic permeability given a predetermined maximum RF antenna power loss.

50. The method of claim 43, wherein the magnet and the antenna possess an elongation direction, the radio frequency magnetic field and the static magnetic field being perpendicular to the elongation direction.

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